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THE FORMATION OF THE MILKY WAY DISK

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Abstract. We present theoretical results on the galactic abundance gradients of several chemical species for the Milky Way disk, obtained using an improved version of the two-infall model of Chiappini, Matteucci, & Gratton (1997) that incorporates a more realistic model of the galactic halo and disk. This improved model provides a satisfactory fit to the elemental abundance gradients as inferred from the observations and also to other radial features of our galaxy (i.e., gas, star formation rate and star density profiles). We discuss the implications these results may have for theories of the formation of the Milky Way and make some predictions that could in principle be tested by future observations.

1. Results and Discussion

In this work we adopt a chemical evolution model (see Chiappini, Matteucci, & Romano 2000) that assumes two main accretion episodes for the formation of the Galaxy: the first one forming the halo and bulge in a short timescale followed by a second one that forms the thin-disk, with a timescale which is an increasing function of the Galactocentric distance (being of the order of 7 Gyrs at the solar neighborhood). The present model takes into account in more detail than previously the halo density distribution and explores the effects of a threshold density in the star formation process, both during the halo and disk phases. The model also includes the most recent nucleosynthesis prescriptions concerning supernovae of all types, novae and single stars dying as white dwarfs. In the comparison between model predictions and available data, we have focused our attention on abundance gradients as well as gas, star and star formation rate distributions along the disk, since this kind of model has already proven to be quite successful in reproducing the solar neighborhood characteristics.

We suggest that the mechanism for the formation of the halo leaves heavy imprints on the chemical properties of the outer regions of the disk, whereas

the evolution of the halo and the inner disk are almost completely disentangled. This is due to the fact that the halo and disk densities are comparable at large Galactocentric distances and therefore the gas lost from the halo can substantially contribute to build up the outer disk. We also show that the existence of a threshold density for the star formation rate, both in the halo and disk phase, is necessary to reproduce the majority of observational data in the solar vicinity and in the whole disk. In particular, a threshold in the star formation implies the occurrence of a gap in the star formation at the halo-disk transition phase, in agreement with recent data.

Our main conclusions are:

- Our best-model predicts gradients in good agreement with the observed ones in PNe, H II regions and open clusters.
- The outer gradients are sensible to the halo evolution, in particular to the amount of halo gas which ends up into the disk. This result is not surprising since the halo density is comparable to that of the outer disk, whereas is negligible when compared to that of the inner disk. Therefore, the inner parts of the disk ($R < R_\odot$) evolve independently from the halo evolution.
- We predict that the abundance gradients along the Galactic disk must have increased with time. This is a direct consequence of the assumed “inside-out” scenario for the formation of the Galactic disk. Moreover, the gradients of different elements are predicted to be slightly different, owing to their different nucleosynthesis histories. In particular, Fe and N, which are produced on longer timescales than the α -elements, show steeper gradients. Unfortunately, the available observations cannot yet confirm or disprove this, because the predicted differences are below the limit of detectability.
- Our model guarantees a satisfactory fit not only to the elemental abundance gradients but it is also in good agreement with the observed radial profiles of the SFR, gas density and the number of stars in the disk.
- Our best model suggests that the average $\langle [\alpha/\text{Fe}] \rangle$ ratios in stars slightly decrease from 4 to 10 kpc. This is due to the predominance of disk over halo stars in this distance range and to the fact that the “inside-out” scenario for the disk predicts a decrease of such ratios. On the other hand we predict a substantial increase (~ 0.3 dex) of these ratios in the range 10–18 kpc, due to the predominance, in this region, of the halo over the disk stars.

Finally, we conclude that a relatively short halo formation timescale ($\simeq 0.8$ Gyr), in agreement with recent estimates for the age differences among Galactic globular clusters, coupled with an “inside-out” formation of the Galactic disk, where the innermost regions are assumed to have formed much faster than the outermost ones, represents, at the moment, the most likely explanation for the formation of the Milky Way. This scenario allows us to predict abundance gradients and other radial properties of the Galactic disk in very good agreement with observations. More observations at large Galactocentric distances are needed to test our predictions.

References

- Chiappini, C., Matteucci, F., & Gratton, R. 1997, *ApJ*, 477, 765
 Chiappini, C., Matteucci, F., & Romano, D. 2000, *ApJ*, (submitted)